Smart structures for aircraft design

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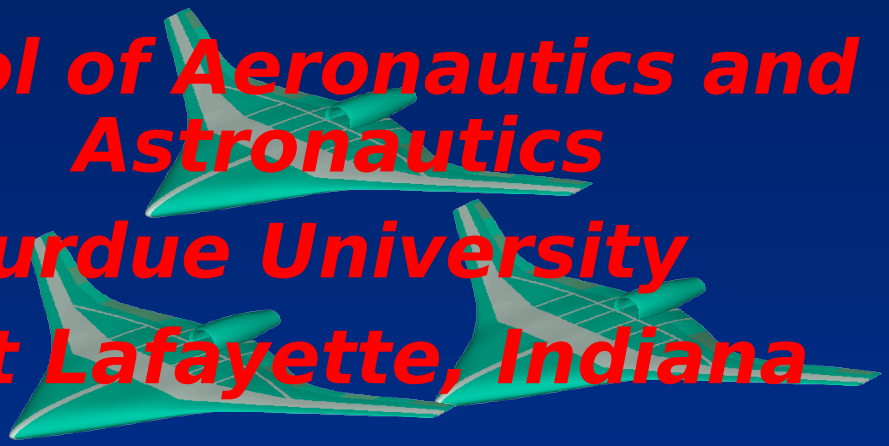


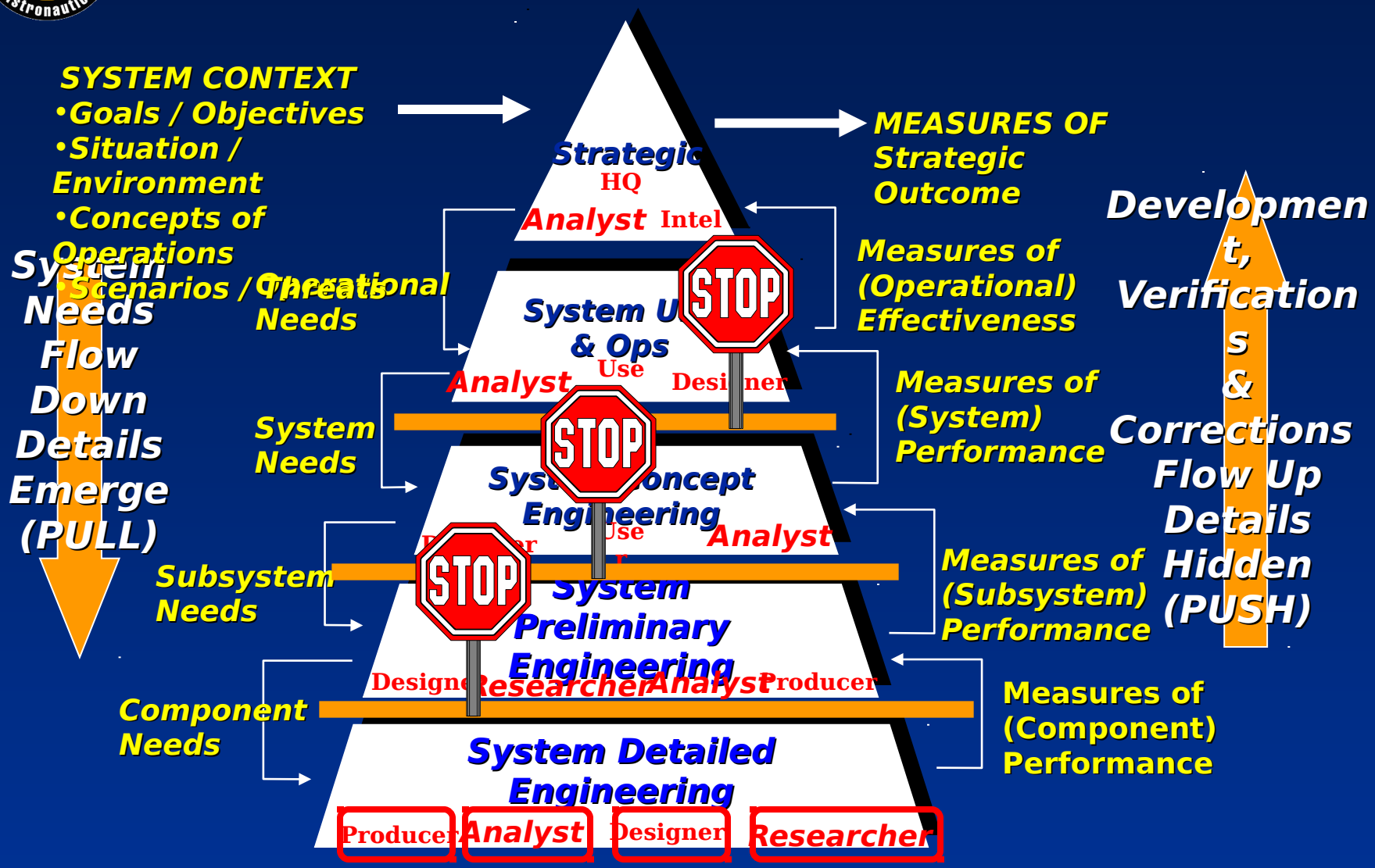
"The relationship between research and prosperity is as predictable as that between prayer and deliverance."

Air Vehicles Directorate
Wright-Patterson AFB, Ohio
June 6, 2000

Overview & purpose

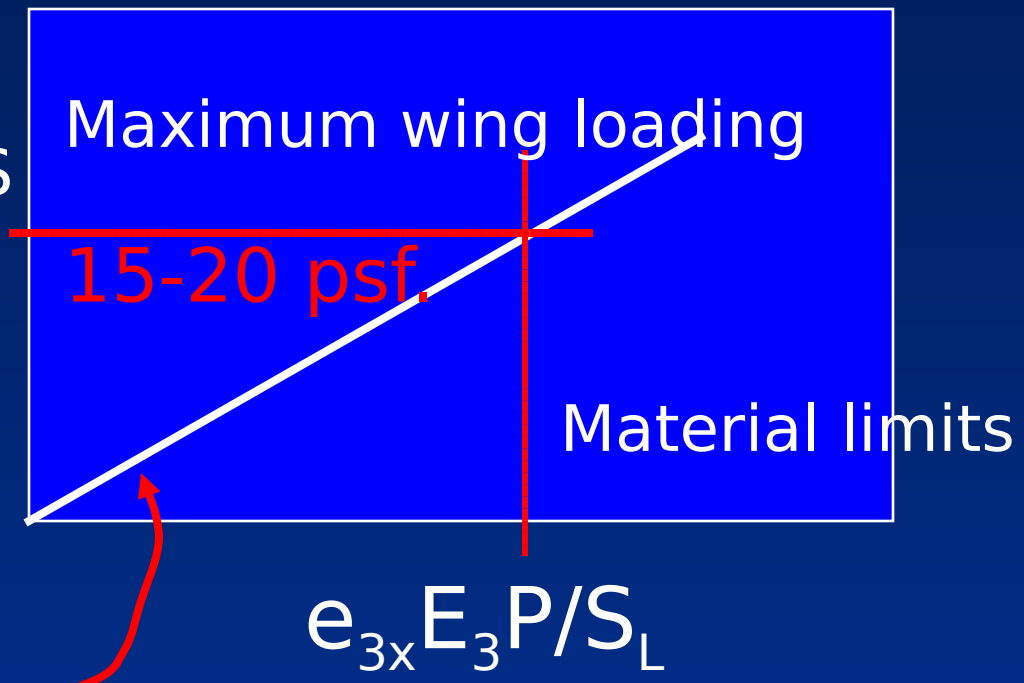
- *Philosophy and experience-an example of piezoaeroelasticity and control*
- *Lessons to be learned - “the innovators dilemma”*
- *What has changed - UAV opportunities*
- *Smart aero/structures development-compliant control surfaces*
- *New technology and analytical tools enlarge systems study possibilities*
- *Action items*

GOAL - AN INTEGRATED, ITERATIVE PROCESS LEADING TO BALANCED SYSTEM REQUIREMENTS & SUCCESSFUL PRODUCTS



Using piezoelectric sheets to bend and twist box beams

Wing cross-section



e_{3x}~piezo stress factor=$d_{31}E_{11}$

E_3=operational voltage

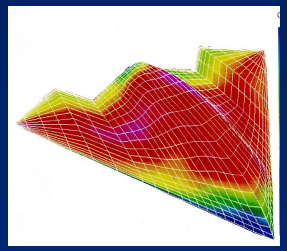
S_L=twist rate ratio~lift

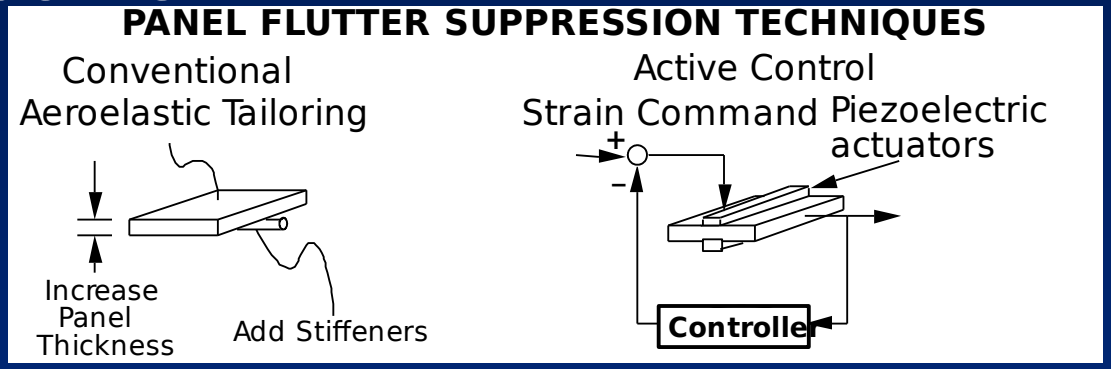
P=wing tailoring parameter

Slope ~ (aspect ratio, thickness ratios, box aspect ratio)

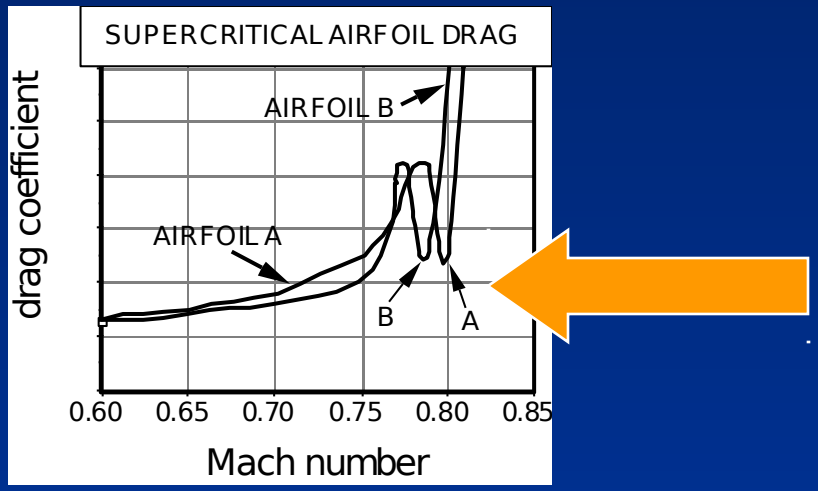
Active piezo elements

- Panel flutter active control





- Transonic drag reduction by reshaping upper surface of airfoils



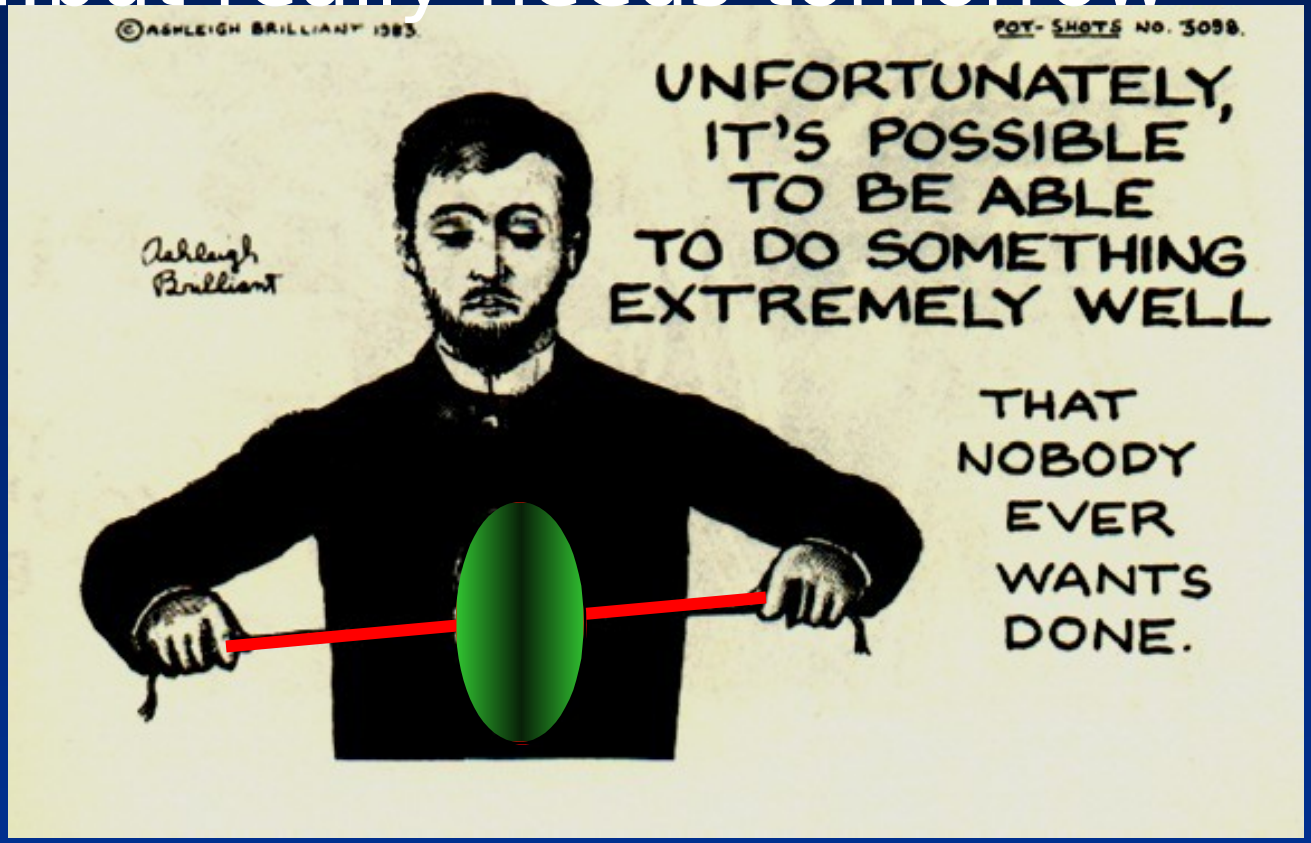
The innovator's dilemma - disruptive technologies Christiansen - Harvard

- Sustaining technologies improve the performance of established products
- Products grow more expensive

- In the near term - disruptive technologies bring worse product performance to the market, but they have features that a few fringe/new customers value. (cheaper, simpler, smaller, more convenient)

Getting something done that nobody really wants - today

- …but really needs tomorrow


©ASHLEIGH BRILLIANT 1983
POT-SHOTS NO. 3098.
UNFORTUNATELY, IT'S POSSIBLE TO BE ABLE TO DO SOMETHING EXTREMELY WELL
THAT NOBODY EVER WANTS DONE.

Disruptive technologies

- Companies depend on customers and investors
- Management has well-developed systems for killing ideas that customers don’t want – until they want them - then it is too late.
- Small markets don’t solve the growth needs of large companies.
- Disruptive technologies emerge from small companies not large companies with well-established markets.

Disruptive technologies II

- There are strong first mover advantages.
- Technology supply may exceed market demand in mainstream markets- particularly air vehicles.
- Disruptive technologies can become fully performance competitive if a key ingredient is added.
- UAV’s have the characteristics of a DT

Exploiting new markets

- Understand where disruptive technologies might strike next and attempt to plan. This requires large amounts of “unproductive” work.

- Plan to learn and discover rather than produce and execute.

UAV's present the largest aero/system challenge faced by the USAF today

- 3D’s - perform “Dull, Dirty, and Dangerous” missions
- 4th D - Different - perform missions not possible with manned aircraft-analogous to Mars mission approach
- Cost - provide a lower-cost alternative to manned aircraft - these vehicles can be used asymmetrically against the United States

Unmanned Air Vehicles background - studies

- Air Force New World Vistas 1995 - UAVs mentioned as concepts
- Air Force SAB study 1996 - well-thought out
  - ***result - DARPA/Air Force SEAD vehicle***
- DARPA Summer Study 1997
  - ***result - not much - tried to push a single technology***
- NRC/AFOSR Study 1998 - a good team
  - ***good recommendations - no report***
- All 4 called for developing alternatives to manned aircraft for focused, selected missions

Tomorrow's programs-combat

- UAV's must be smaller, reliable, easy to maintain, and have lower peacetime operational costs
- 80/50 rule - 80% capability at 50% cost of combat aircraft
- Combat missions depend on continued development in three areas
  - small size precision weapons
  - reliable software, miniaturized electronics
  - highly capable communications network

Today's UAV Programs

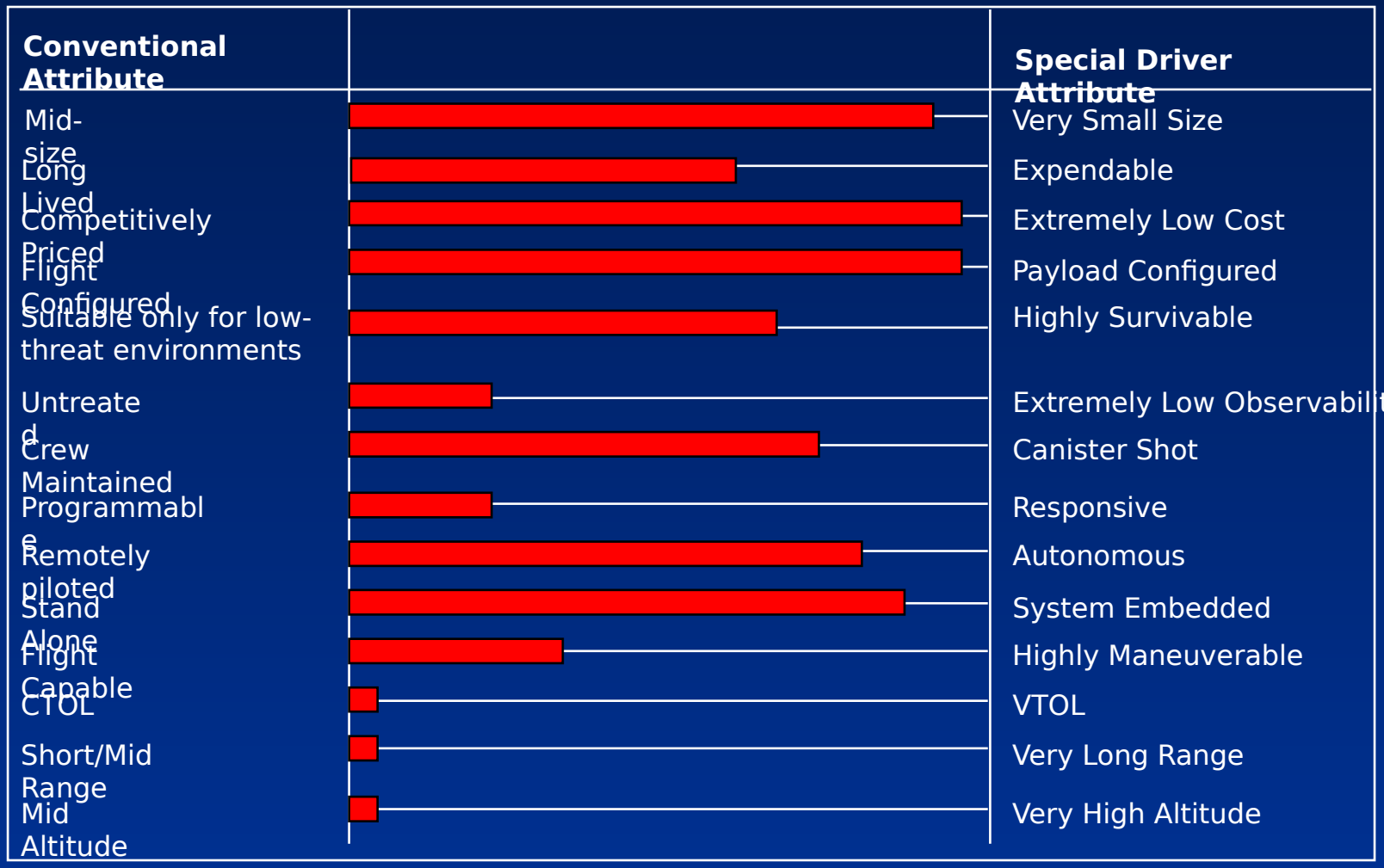
- Combat
  - ***UCAV (DARPA/USAF)***

Boeing UCAV 2000

SAB concept 1996

What's new?

Small (almost) expendable UAV



Example - an add-on device to reduce drag

- Use compliant actuators around the wing edges
- sources - Boeing transport study (with patent application) - Northrop/Grumman smart wing development – published compliant surface technology
- Conclusion - lots of synergism - no one person responsible

Induced drag the issue - does structural stiffness make a difference to performance?

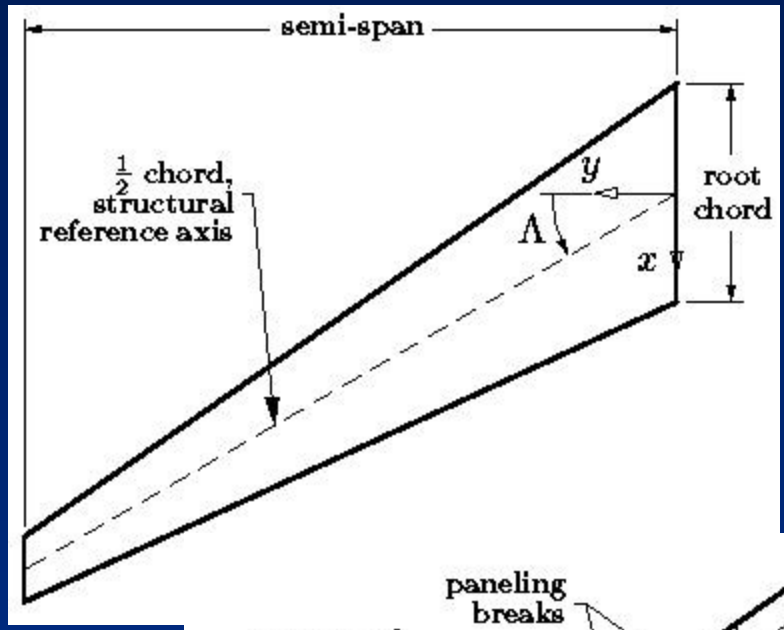
$$C_{D,i} = \frac{C_L^2}{\pi AR}(1+\delta) = \frac{1}{\pi q^2 S}\left(\frac{W}{b}\right)^2(1+\delta)$$

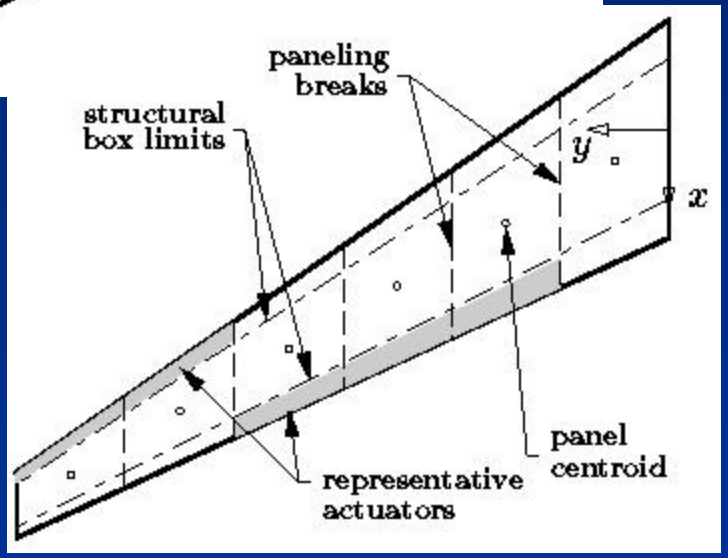
$$D_i = qS\frac{C_L^2}{\pi AR}(1+\delta) = \frac{1}{\pi q}\left(\frac{W}{b}\right)^2(1+\delta)$$

How is this term affected by structural deformation?

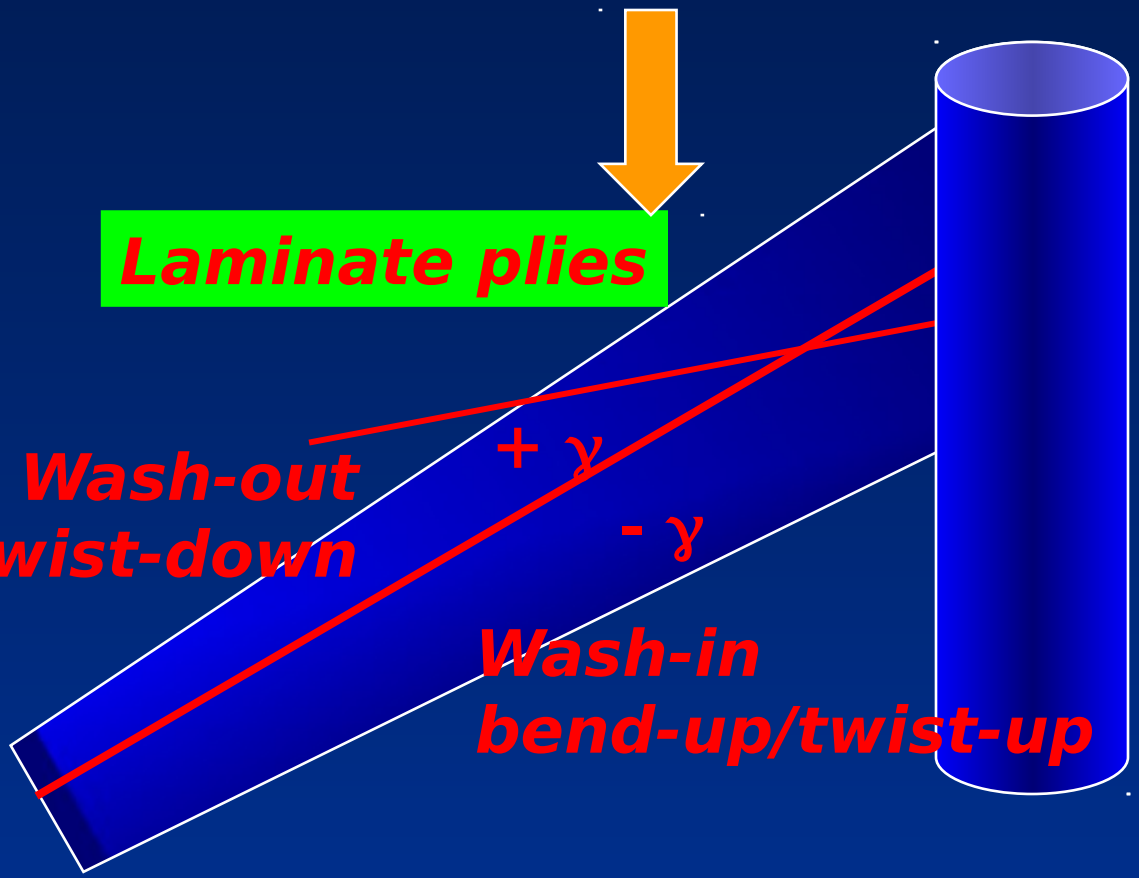
Wing Geometry

- Compliant actuators distributed on leading and trailing edges
- Cantilevered wing
  - *fixed wing loading*
- Stiffness coupled box beam
  - *Composite laminate - plies in upper and lower skins*

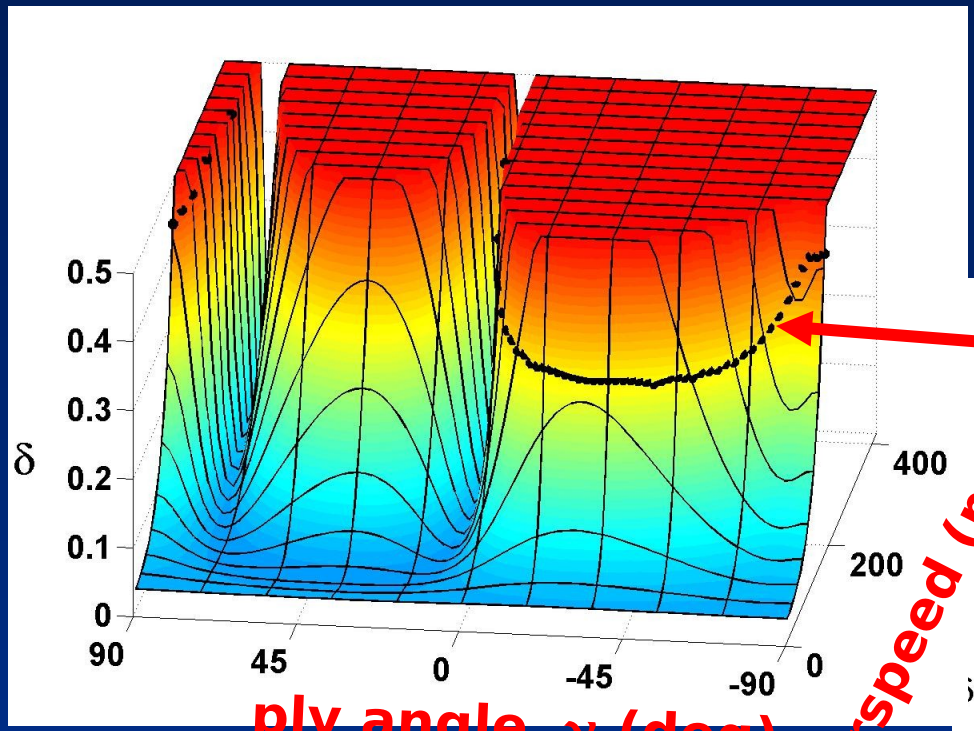




Ply sign convention



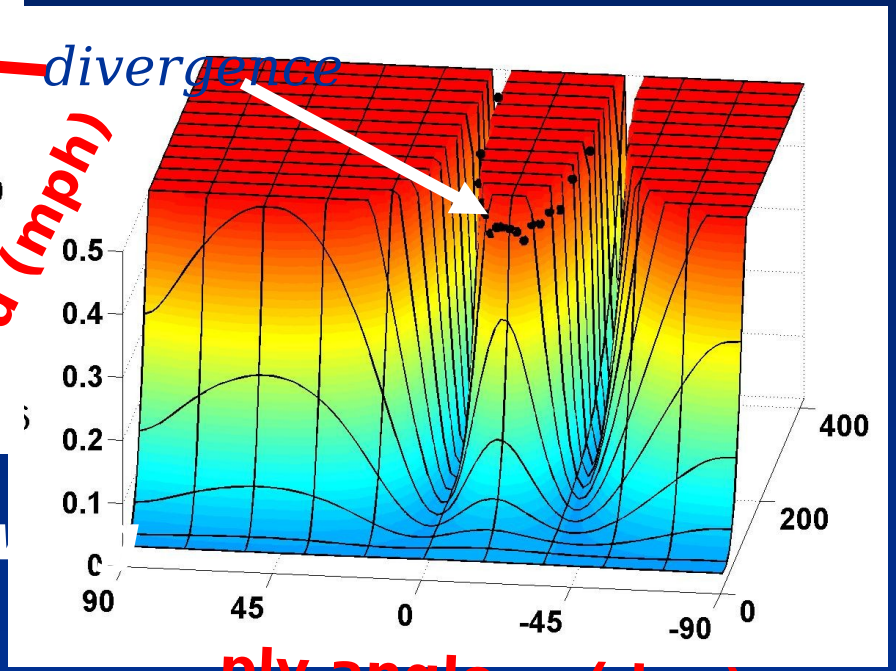
Aeroelastic Tailoring
Drag Control Design Spaces



Unswept, untapered w

30° aft sweep

divergence

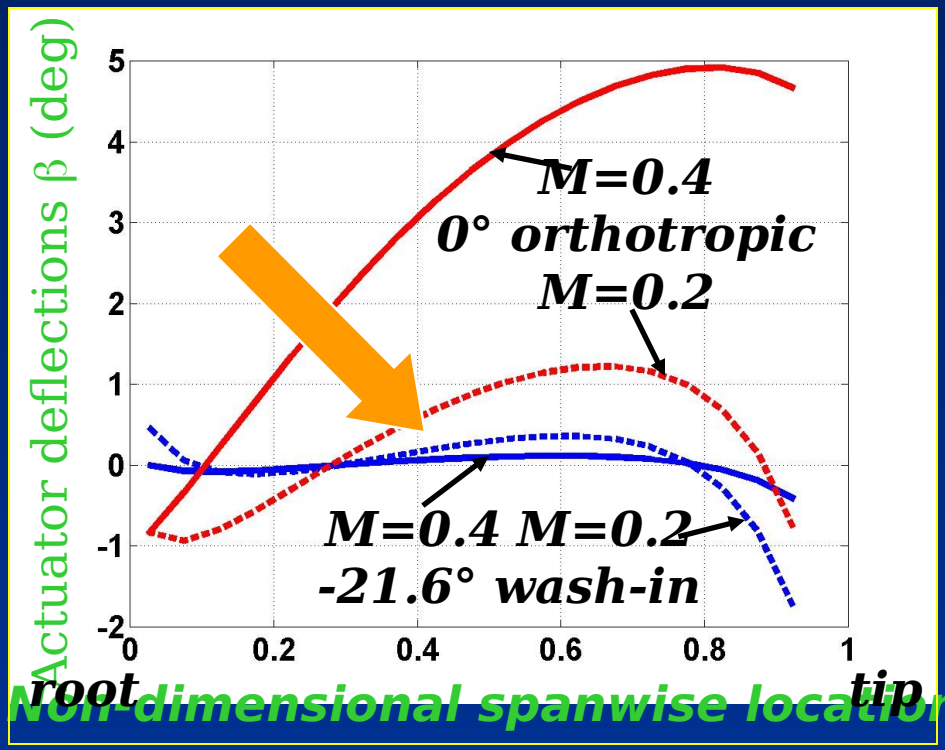


Active Control of Induced Drag

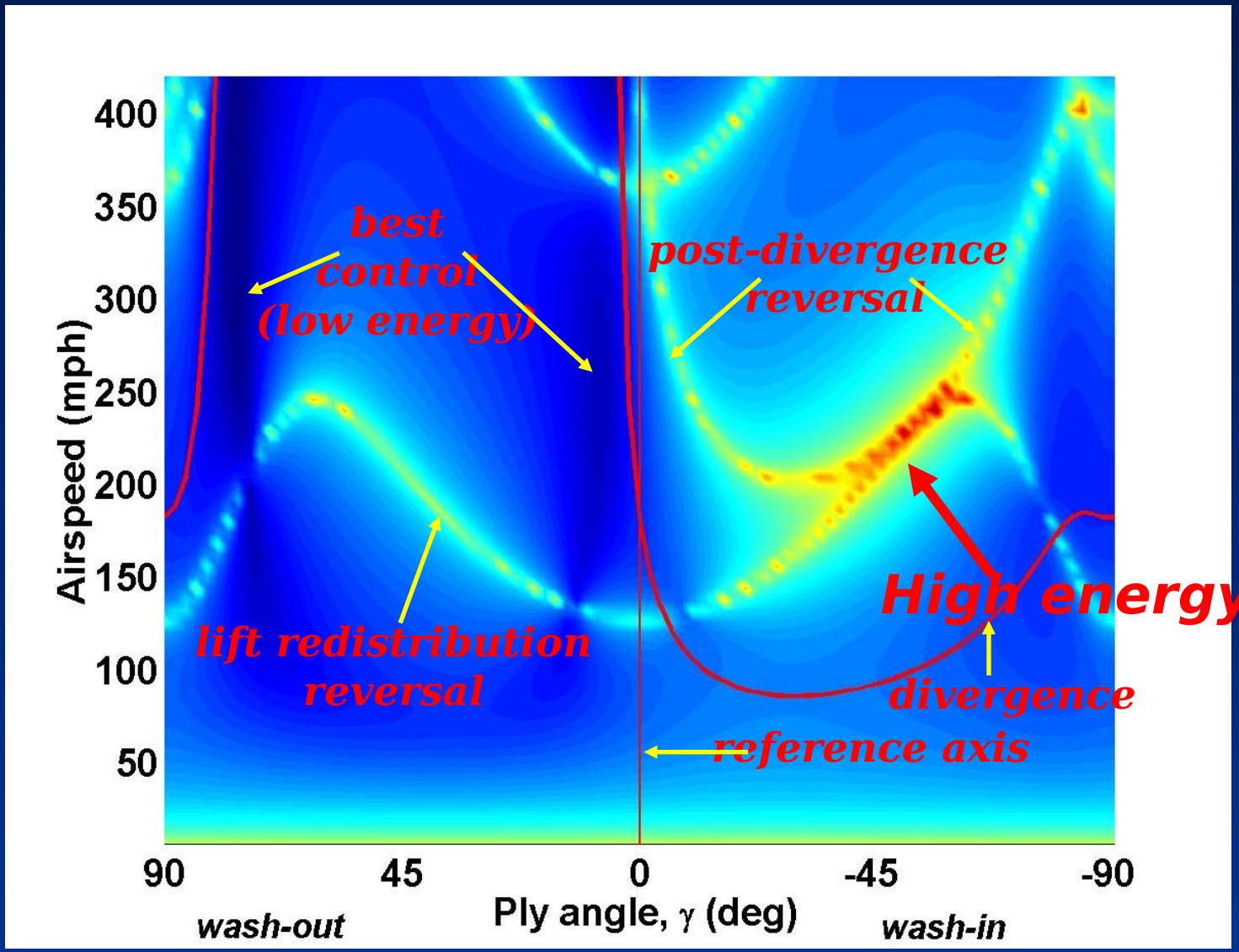
- Aeroelastic tailoring can only limit induced drag increases.
  - δ is never zero (distribution is never parabolic)
  - δ increases with airspeed for all laminate designs
- Control actuator deflection reshapes lift distribution on a wing
  - Optimal control surface deflections can reduce δ
  - Optimal combinations of aeroelastic tailoring and control surface deflections give smaller δ with less energy

Full Span Actuator Deflections

- Optimal laminate stiffness tailoring can make lift distribution control easier - less energy
- Example wing:
  - 30° aft swept wing
  - taper ratio=0.3
  - outer 60% of laminate plies rotate as a set
  - smaller deflections for wash-in laminates



Active Induced Drag Control Design Space



How do we put these things together?

Requirements - a real tea
with experience, tools a

An example of innovative research direct

Genetic Algorithm Approaches to Smart Actuator Placement for Aircraft Flight Control

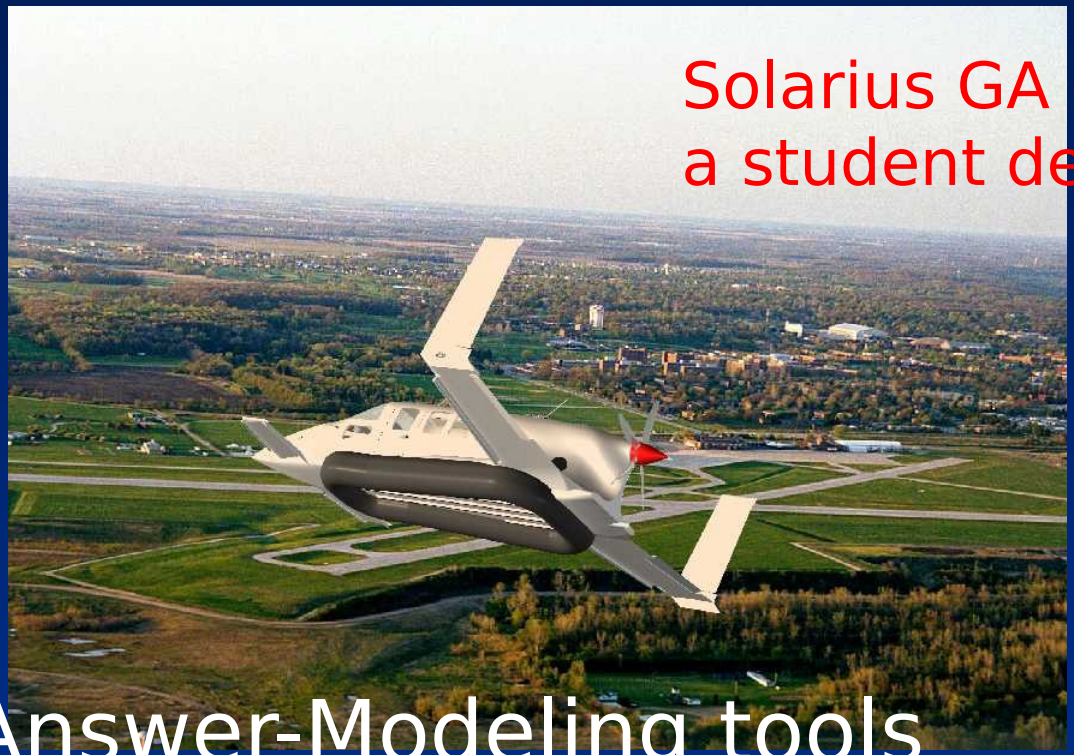
Andrea Cook, Graduate Research Assistant

William A. Crossley, Assistant Professor

School of Aeronautics and Astronautics

Purdue University

What has changed?

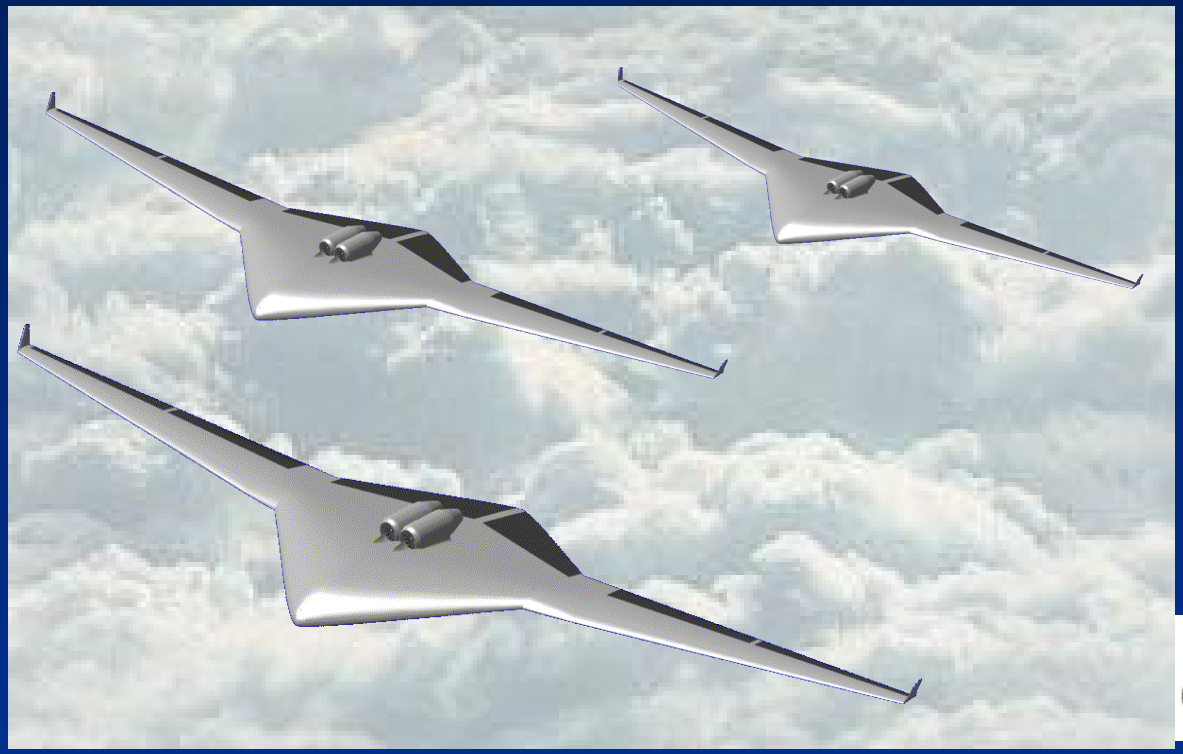


Solarius GA design
a student design

Answer-Modeling tools that give us the ability to learn and then discard

OSCAR - AFRL/VA/Purdue University sponsored study

Omni-directional SensorCraft for Aerial Reconnaissance



Jason Helms

Tulin Kayir

Eric Martin

Brian Prock

Andrew Remson

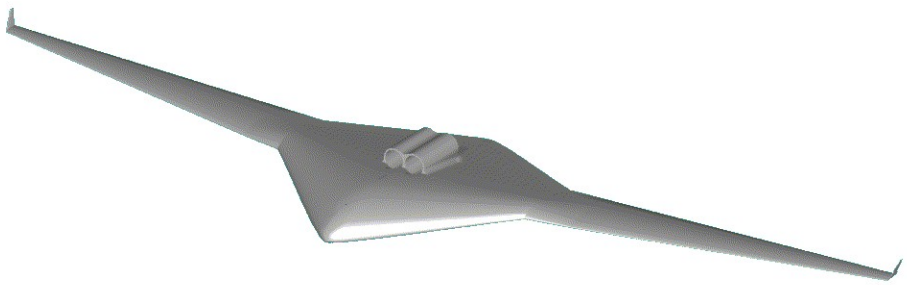
Clint St. John

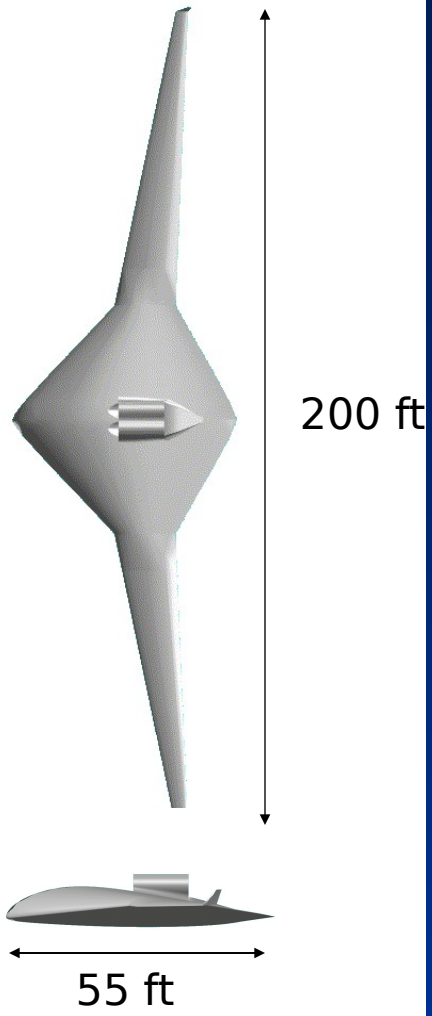
Purpose & Mission

- *Purpose*: *Affordable, reliable observation and communications platform for United States Air Force*
- *Mission:*
  - ***support 30x30 ft X-band and 200 ft VHF antennae***
  - ***operate at 65,000 ft***
  - ***loiter 40 hrs***
  - ***range radius 3000 nm***
  - ***6000 ft runway***

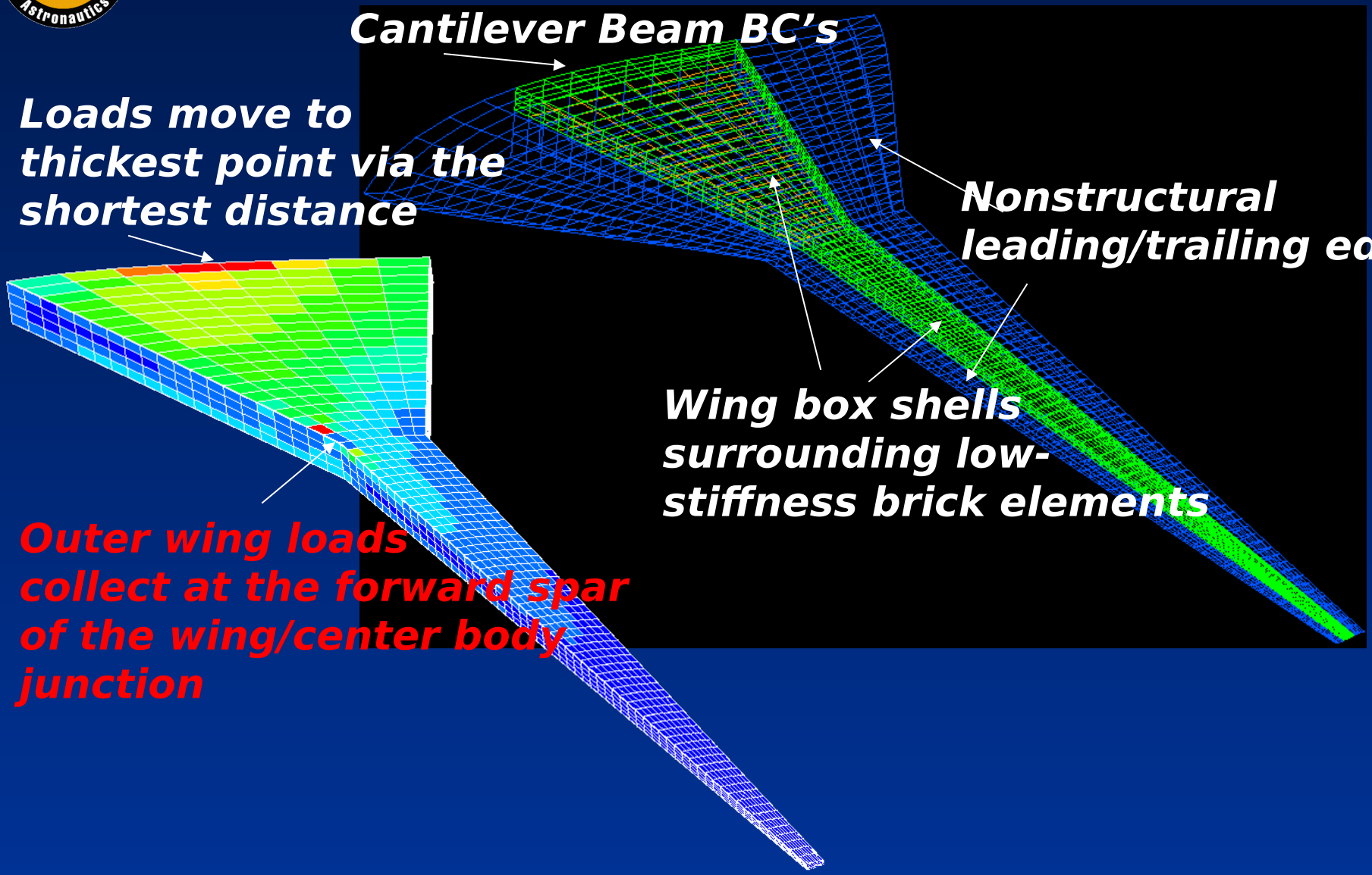
Aircraft Description

- TOGW = 88000 lb
- W/S_{max} = 27 lb/ft^2
- Loiter Time = 40 hrs
- Range = 3000 nm

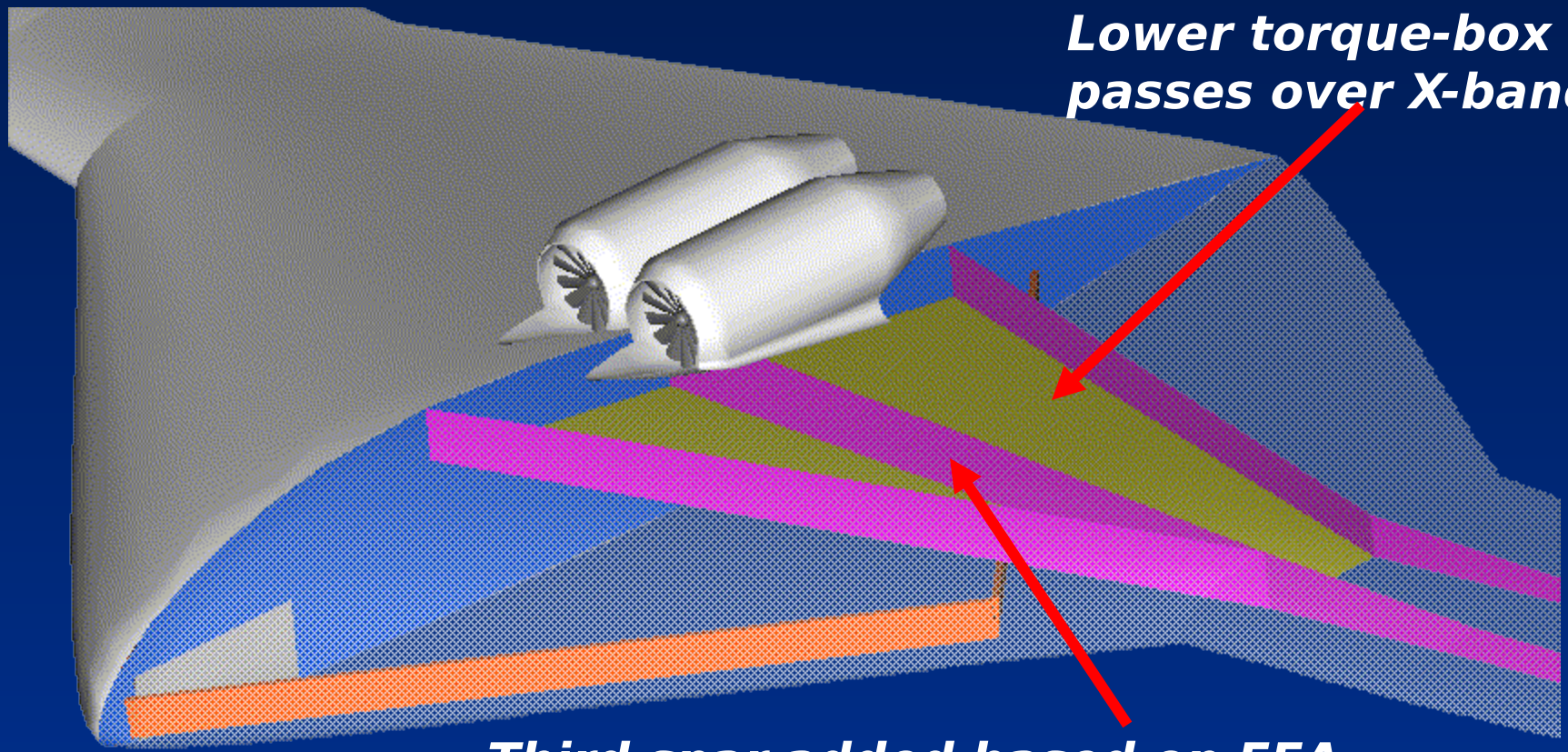




Load Path Determination


Cantilever Beam BC's
Loads move to thickest point via the shortest distance
Nonstructural leading/trailing edg
Wing box shells surrounding low-stiffness brick elements
Outer wing loads collect at the forward spar of the wing/center body junction

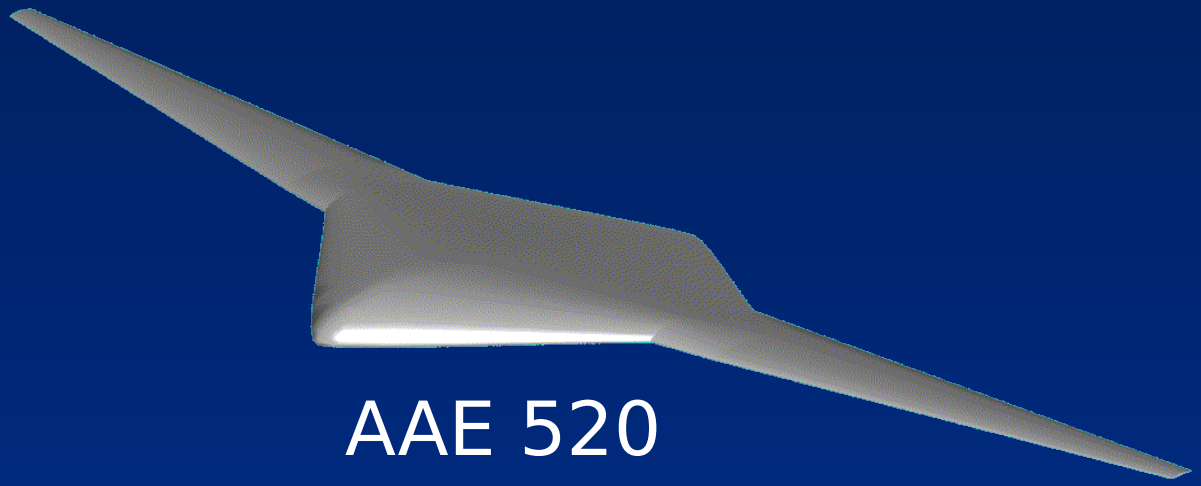
Internal detail



Lower torque-box s
passes over X-band

Third spar added based on FEA
Runs from 50% chordline at centerline to
the forward spar at wing/center body jun

Wind Tunnel Testing of Diamond-Wing Body for Stability Analysis



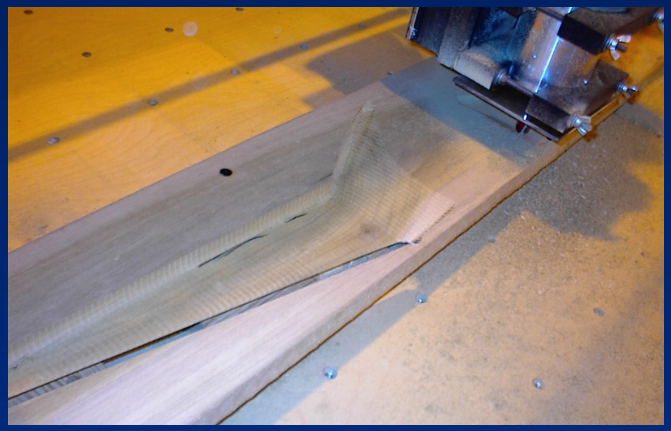
AAE 520

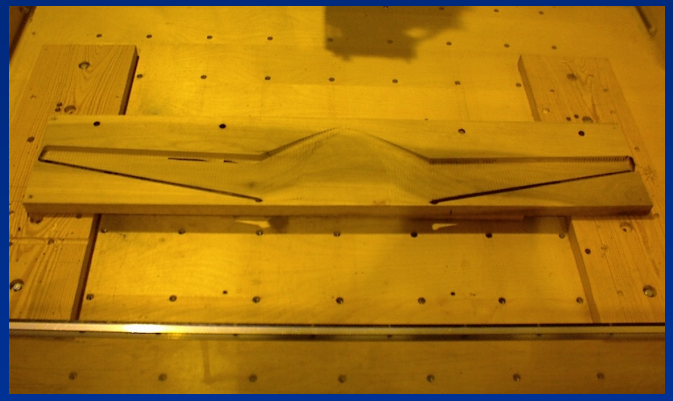
Eric Martin

Brian Prock

CNC Milling

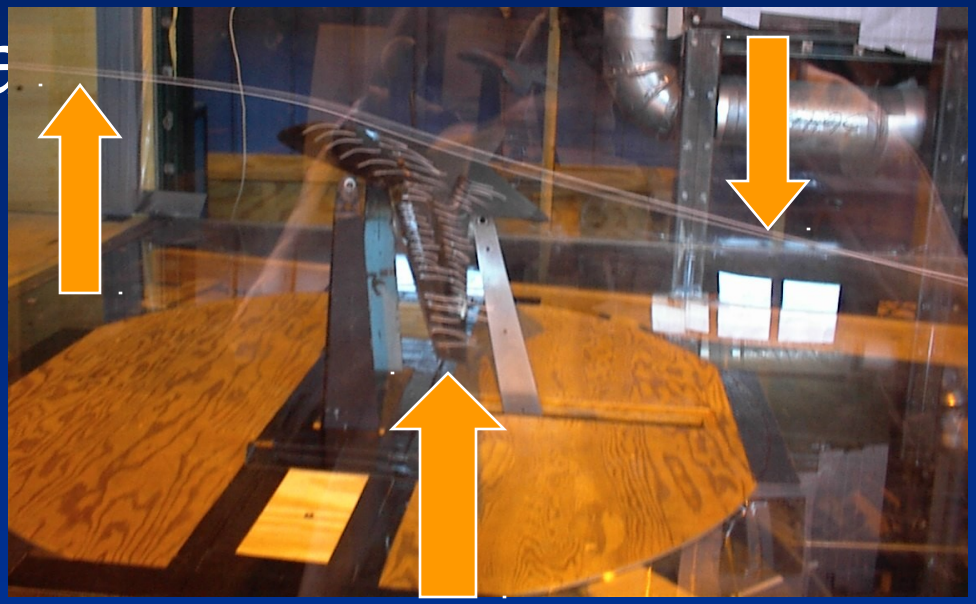
Solid model I-DEAS geometry exporte
directly to CNC milling toolpaths





Flow Visualization

- *Smoke wand used for flow visualization*
- *String wand displays vortices and separation*
- *Model tufts a*



Action-adopt the innovator's dilemma approach

- Challenge a team to put together bold, different missions that favor UAV's - *e.g.* swarming…..
- Define system and link vehicle requirements - examine opportunities for smart materials and actuators
- Develop systems designs that use advanced actuators and concepts "on the shelf"
- Benchmark these designs against other possibilities